Topic 2. Indoor environment

THERMAL COMFORT IN LECTURE HALLS IN THE TROPICS

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ABSTRACT

A field study was conducted in six lecture halls DK1-DK6 of the Faculty of Engineering at University of Malaya, Kuala Lumpur to assess the thermal conditions during the lecture session. Comfort parameters were measured to analyze the acceptability of the thermal comfort simultaneously when 178 students answered a survey questionnaire on their thermal perception/sensation of the indoor climate. The measured data includes air temperature, mean radiant temperature, relative humidity, air velocity and personal variables. The response of the occupants in the lecture hall DK6 only is fulfilling the ASHRAE Standard 55, because PPD in this lecture hall is 5.8, whereas that in other lecture halls is above 10. Besides, AMV and PMV have been compared. Fanger's model was used to calculate the neutral operative temperature (24.6°C), whereas the questionnaire data used in the TSV analysis gives higher value (25.3°C) for the neutral operative temperature. This is in good agreement with the neutral operative temperature (25.4°C) for Hong Kong. The humidity in the lecture halls DK1, DK4 and DK5 was below and that of the lecture halls DK2, DK3 and D6 was above the recommended range 50-60% RH. The air velocity in all the six lecture halls was below 0.2 m/s for normal room air distribution. The air velocity in the lecture hall DK6 was 0.08 m/s, which is too low. Metabolism in each hall was $\leq$1.2 met for light and primarily sedentary activity. The clo value in each lecture hall was above 0.55 clo for average people. Findings of this field study are useful in designing HVAC systems with energy savings for university lecture halls in the tropics.

KEYWORDS

Predicted mean vote, Thermal sensation vote, Predicted percentage of dissatisfied, Energy saving

NOMENCLATURE

AMV	Actual Mean Vote
AC	Air-conditioning
ACMV	Air-conditioning and Mechanical Ventilation
HVAC	Heating, Ventilating and Air-conditioning
IAQ	Indoor Air Quality
NV	Natural Ventilation
PMV	Predicted Mean Vote
PPD	Predicted Percentage of Dissatisfied
RH	Relative Humidity
TC	Thermal Comfort
TSV	Thermal Sensation Vote

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INTRODUCTION

The tropical country Malaysia possesses a hot and humid climate throughout the year. Its yearly mean temperature is 26-27°C with relative humidity (RH) of 70-90%. Air - conditioning (AC) and ventilation systems are incorporated inside the buildings to control temperature and comfort or good health and thereby the productivity of the occupants. Yet, some people are found to suffer from headaches, nausea, irritations of eyes, fatigue, rash, etc, what is called Sick Building Syndrome, caused by improperly controlled RH (Sookchaiya et al., 2010). The students' attention, concentration, learning, hearing and performance can be greatly enhanced if high level of indoor air quality (IAQ) is maintained in the lecture halls. Thermal comfort (TC) is an important factor of IAQ. It must be paid great attention because of the negative impact on learning and potential for energy conservation via careful temperature control. Staff and students in a university spend indoor 90% of their time in the campus. The pollutants in a lecture hall may be sometimes more than 100 times higher than the outdoor. Compared to an office building a lecture hall is extremely overcrowded during the occupied period. IAQ problems are generally due to improper ventilation in the lecture halls (Cheong & Lau, 2003). The air-conditioning and mechanical ventilation (ACMV) systems in the tropics can be very different from those of the temperate climate.

Thermal Comfort

TC involves control of temperature, humidity, air motion and non-environmental factors such as dress and activity level of the occupants (McQuiston et al., 2005). TC is maintained when the heat generated by human metabolism and other components such as electrical instrument are allowed to dissipate, thus maintaining thermal equilibrium with the surroundings. Heat gain or loss beyond this will generate a sensation of dissatisfaction.

The ideal standard for TC can be defined by the operative temperature. Based on ASHRAE Standard 55 (2004), "Thermal Environmental Conditions for Human Occupancy" specifies thermal conditions which will be acceptable to 80% or more occupants in a building if dressed appropriately. According to ASHRAE Standard 55(2004) the acceptable operating temperatures and humidity in summer (light clothing, 0.5 clo) are 24-28°C with 30% RH and 23-25.5°C with 60% RH and air speed of <0.25 m/s (OSH, 2007).

Humidity below 50% RH enhances spreading rate of influenza virus and can cause tissue weakness (Sookchaiya et al., 2010). It also causes discomfort by drying out the mucous membrane, contributing to skin rashes. Due to dry conditions electrostatic charge occurs on both office equipments and their users. Office workers generally feel better when the humidity is kept at about 50% RH. Higher humidity causes the office feel 'stuffy'. Besides, it can contribute to the development of bacterial and fungal growth, especially in sealed buildings (OSH, 2007). Humidity can increase wetness on different areas of the body, leading to a perception of discomfort.

The metabolism rate fluctuates when a person performs certain activity, or under certain environmental conditions. The other personal variable that affects thermal satisfaction is the type and amount of clothing that a person is wearing. ASHRAE Standard 55 (2004) gives the conditions for an acceptable thermal environment. The studies of the TC involve using the ASHRAE thermal sensation scale. This scale is

(+3hot), (+2 warm), (+1 slightly warm), (0 neutral), (-1 slightly cool), (-2 cool), (-3 cold).

Field studies on thermal comfort in tropics

The work Givoni suggests that humidity does not affect much human thermal sensation in hot and humid climate. A new AC design tactic is elevating the summer temperature setting by increasing the air movement (Chow et al., 2010). Field experiments in Taiwan found the neutral operative temperature 25.6°C of AC classrooms whereas that for natural ventilation (NV) classrooms was 0.6°C higher. Other field studies in the tropics also show that the neutral operative temperature of NV buildings is higher than that ogf the AC buildings (Hwang et al., 2006). This is due to human body’s adaptive functions, the occupants are less thermally sensitive in the NV building than in an AC building.

The mean air temperature was 23°C in AC lecture theatre in a university of Singapore. It is recommended to raise the comfort temperature to 25.84°C (Cheong et al., 2003). A field study in Thailand recommended 26°C, 50-60% RH, and 0.2 m/s air speed to be the thermal comfort standard for AC design with clothing insulation of 0.5 clo. The neutral temperature for the people with AC acclimatization behaviour at home and work was 25.4°C (Yamtraipat et al., 2005). For AC chamber with educated Chinese subjects in Hong Kong with clothing level 0.55 clo, metabolic rate 1 met and bodily air speed at 0.2 m/s, the neutral temperature was found around 25.4°C for sedentary working environment (Chow et al., 2010).

The main objectives for this study are:

- To assess the thermal conditions in the lecture halls and compare with the ASHRAE Standard 55 (2004).
- To assess the satisfaction of the occupants on the level of TC in the lecture halls of University of Malaya, Kuala Lumpur with the help of ASHRAE thermal sensation scale used in the votes of TC.
- To determine the neural temperature in the lecture halls.
- To find an innovative AC design technique.

METHODOLOGY

The field study was conducted in six lecture halls, namely, DK1-DK6 at Engineering Faculty, University of Malaya, Kuala Lumpur. DK2 is the biggest lecture hall, while DK1 is the smallest one. The lecture halls were investigated during actual lecture sessions. The subjective assessment-questionnaire survey and the objective indoor environmental data monitoring were conducted simultaneously.

Physical measurement

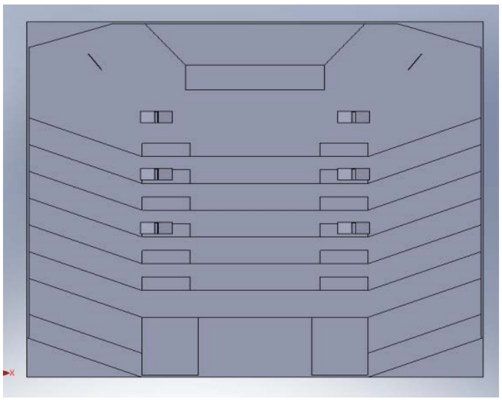

Figure 1. *Layout plan for DK1 with diffusers and return air duct.*

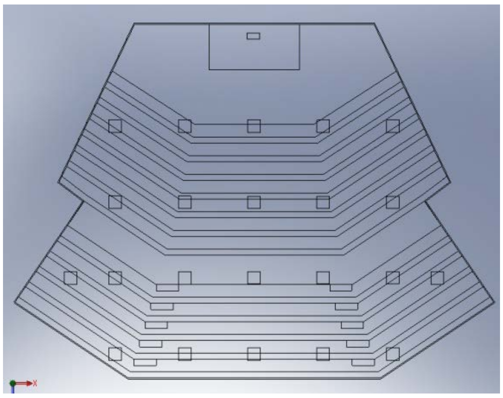

Figure 2. *Layout plan for DK2 with diffusers and return air duct.*

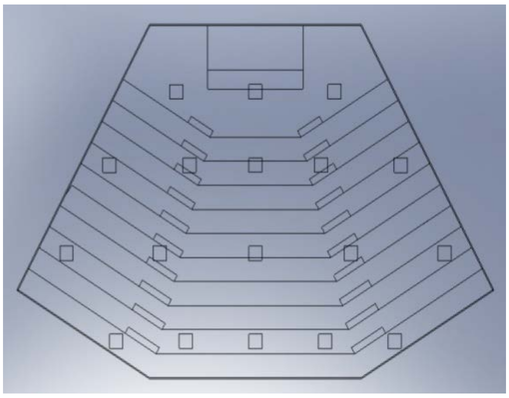

Figure 3*. Layout plan for DK3 with diffusers and return air duct.*

First of all, approval was taken from the lecturers and department for taking the data during the lecture sessions. Then, the plans of the lecture halls, DK1-DK6, with diffusers and the return air ducts were sketched on the paper. Figures 1-6 show the layout plans. Referring to the sketch, 9 to 12 points were selected for each lecture hall considering the students' positions, the collocation of the most crowded zones and the possibility to place the instruments. The time taken for the measurements ranges from 10.00 am to 5.00 pm, and mostly on the sunny days.

Figure 4. *Layout plan for DK4 with diffusers and return air duct.*

Figure 5. *Layout plan for DK5 with diffusers and return air duct.*

The measurements were carried out by using 3 instruments, which are:

i. IAQ Monitor (KANOMAX-model 22111)
- IAQ Monitor (KANOMAX-model 22111) is used for measuring the dry bulb temperature and also the relative humidity of the indoor and outdoor air.

ii. TSI VELOCICALC (Anemometer)
- TSI VELOCICALC (Anemometer) is used for measuring the air flow velocity of indoor air.

iii. Vernon's Globe Thermometer
- Vernon's Globe Thermometer is used for measuring the mean radiant temperature.

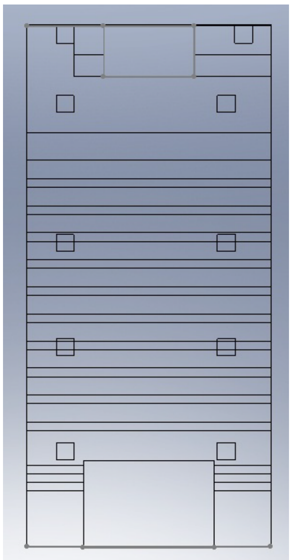

Figure 6. *Layout plan for DK6 with diffusers and return air duct.*

During measurements, the IAQ Monitor and the Anemometer were placed at three different heights of 0.1m, 0.6m and 1.1m heights just above each point on the floor to take readings, as the occupants in the lecture halls were sedentary most of the time. These heights are important to keep the temperature, RH and the air flow velocity within the comfortable range to ensure thermal comfort. Besides, the air temperature at a height of 0.1m above the floor should not exceed 2°C lower than the temperature at the place of the occupant's head. Vernon's Globe Thermometer was used to take reading only once at about 0.6m above each point. Concerning the two significant personal parameters, the metabolic rate was ≤1.2met (light and primarily sedentary activity), and the actual people-clothing were found from the questionnaire.

Questionnaire survey

One hour after the beginning of the lecture, the questionnaires were distributed to the occupants. The purpose of distributing the questionnaires after one hour starting the class is to avoid the effect of the outside environment on the students while entering the lecture halls. The questionnaire comprises only six questions, which cover the gender, age, location, clothing, activity and the level of TC. About 30 students within the age group of 20-24, took part in the survey. These were filled by the students while physical measurements were going on.

RESULTS AND DISCUSSION

Analysis on PMV

Table 1 shows the calculation of PMV and PPD using the ASHRAE TC Tool. The input parameters are the mean values of the data collected in each lecture hall. According to ASHRAE Standard 55 (2004), the acceptable thermal environment for PMV lies between -0.5 and +0.5 and the PPD is below 10. The PPD is related to the PMV and it is based on the assumption that people voting -3, -2, +2 or +3 are dissatisfied. It is observed that only DK6 was in the comfort zone and only 5.8% was expected to express dissatisfaction with the environment. Meanwhile, the others had the PMV values of below -0.5. The clo value in each hall was higher than 0.55 clo for average people (Chow et al., 2010). That is, excessive cooling was being done in the entire six lecture halls at the expense of unnecessary use of energy. Field studies in tropical Thailand show that 50-60% RH is suitable for air-conditioned rooms for thermal comfort (Yamtraipat et al., 2005; Sookchaiya et al., 2010).

Table 1. *PMV and PPD in lecture halls.*

Location	Input Parameters						Outputs	
	Clothing (clo)	Air temp. (°C)	Mean radiant temp. (°C)	Activity (met)	Air speed (m/s)	Relative humidity (%)	PMV	PPD
DK1	0.64	20.84	23.4	1.12	0.20	47.67	-1.10	30.50
DK2	0.61	21.1	22.56	1.03	0.10	62.6	-1.20	35.20
DK3	0.57	22.16	22.65	1.08	0.12	69.31	-0.70	15.30
DK4	0.59	22.27	22.13	1.02	0.12	48.2	-1.30	40.30
DK5	0.64	21.38	22.32	1.05	0.14	48.96	-1.00	26.10
DK6	0.60	24.86	25.38	1.10	0.08	62.4	0.20	5.80

Analysis on TSV

Table 2 shows the profile of Thermal Sensation Vote (TSV) on the ASHRAE scale for each lecture hall at various temperatures. The TSV for DK6 was the closest to 0 (neutral). It implies that the occupants felt most comfortable in DK6 compared to other lecture halls. The other lecture halls had the TSV values between -0.93 to -1.77. It shows that the occupants felt 'slightly cool' or 'cool' in those lecture halls. This is in accordance with the operative temperature data. The operative temperatures of DK1 to DK5 are much lower than that of DK6. Therefore, the majority of the occupants preferred operative temperature of around 25.1°C.

Table 2. *AMV and TSV in lecture halls.*

Location	Operative temperature °C)	AMV	Votes on ASHRAE Thermal Sensation Scale							
			-3	-2	-1	0	1	2	3	Total
DK1	21.84	-1.77	7	12	3	2	2	0	0	26
DK2	21.85	-1.23	0	13	13	3	0	1	0	30
DK3	22.45	-1.04	2	6	13	3	1	0	1	26
DK4	22.20	-1.19	0	8	15	3	0	0	0	26
DK5	21.85	-0.93	1	5	15	5	2	0	0	28
DK6	25.10	-0.05	0	2	16	10	10	4	0	42
Total			10	46	75	26	15	5	1	178

Prediction of neutral temperature

Figure 7 and Figure 8 show the graphs of regression of PMV and operative temperature, and the regression of TSV and operative temperature respectively. From the graphs, the neutral temperature based on PMV regression is 24.6°C and that based on TSV regression is 25.3°C. This is in good agreement with the neutral operative temperature 25.5°C of AC chamber in Hong Kong of Chow et al. (2010).

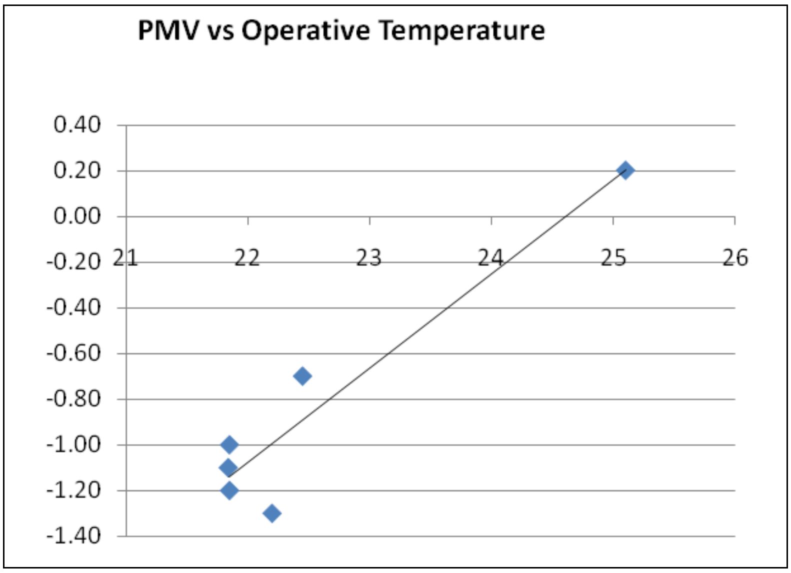

Figure 7. *Graph of PMV vs operative temperature.*

The same thermal comfort standard of 26°C neutral operative temperature, humidity at 50 - 60% RH and 0.2 m/s bodily air speed with ≤ 1.2 met activity level and 0.5 clo light clothing of Thailand for AC design is applicable for the lecture halls at University of Malaya also. This 26°C is also the recommended temperature for thermal comfort for Malaysia, and aligns well with the value 25.82°C calculated by Auliciems' equation (Daghigh & Sopian, 2009). According to ASHRAE 55 (2004), the acceptable summer maximum comfort temperature is 27.5°C (Fanger, 1970). By Humphreys, raising the comfort temperature from 26°C to 27.5°C requires an air speed of 0.36 m/s (Nicol, 2004).

As an innovative approach the set point neutral temperature of the AC system of the lecture halls at University of Malaya could be the maximum permissible 27.5°C with the humidity 50-60%RH, if the air speed is raised to 0.36 m/s with, the personal variables being ≤ 1.2 met and 0.5 clo. The air speed of 0.36 m/s will not create any distraction even in tasks requiring sustained attention. Moreover, as the lecture halls during occupied period are crowded zones, this air speed of 0.36 m/s is helpful to improve IAQ. It may be mentioned that an increase in temperature indoor setting of 1.5°C gives 15.8% energy saving (Daghigh & Sopian, 2009).

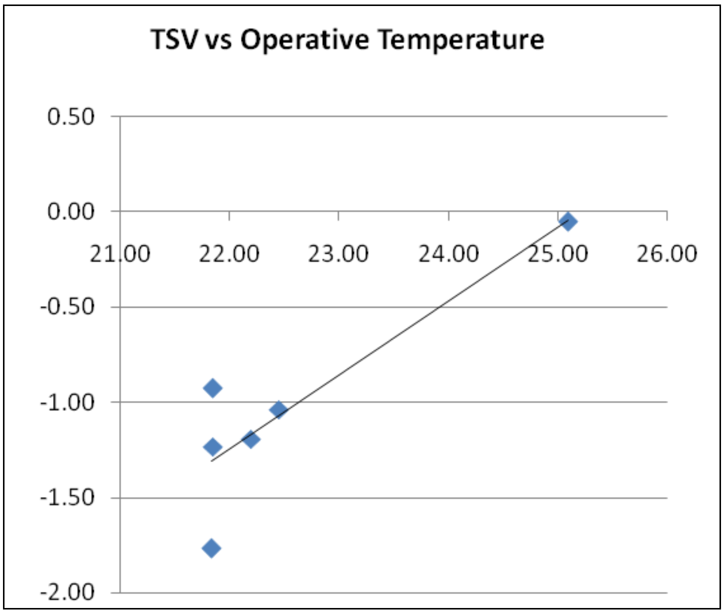

Figure 8. *Graph of TSV vs operative temperature.*

CONCLUSIONS

The study showed that only one out of six lecture halls had thermal conditions falling within the comfort zone of ASHRAE Standard 55 (2004). Similar results were obtained by TSV analysis, showing majority of the occupants felt the lecture halls ‘slightly cool’ and ‘cool’.

The neutral temperature obtained by regression of TSV and operative temperature was 25.3°C. It was 0.7°C higher than that obtained by regression of PMV.

It is recommended that the preferred operative temperature in lecture hall should be 25.3°C in order to make the occupants feel comfortable. It is in good agreement with the neutral operative temperature (25.4°C) for Hong Kong.

To promote sustainable AC design, the direction should be increasing the air speed rather than reducing the air temperature and humidity to achieve the same level of comfort sensation. Energy saving would be greatly enhanced if the temperature and the humidity is set to the neutral operative temperature 27.5°C and 60% RH, the air speed being 0.36m/s with ≤1.2 activity level for sedentary working environment and light clothing insulation of 0.5 clo. Provisions should be there for locally adjustable airflow devices such as miniature fans in meeting individual preferences.

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